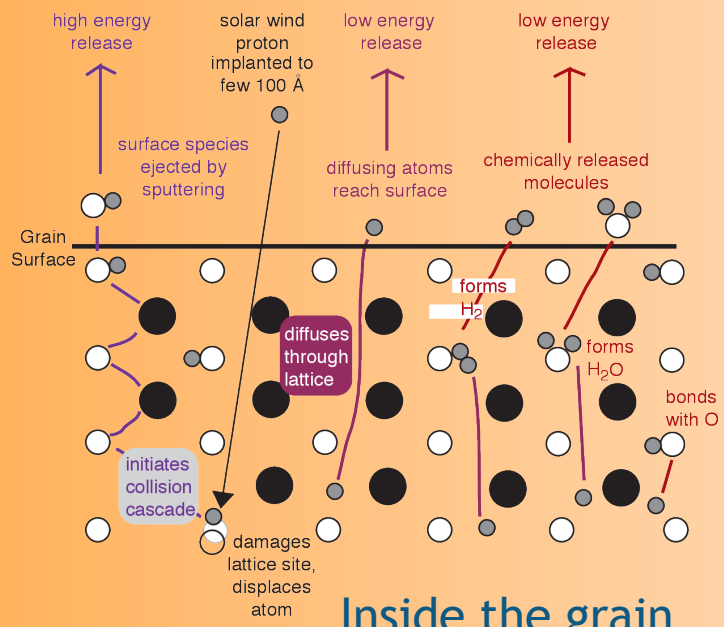
# Solar Wind Access to Lunar Regolith

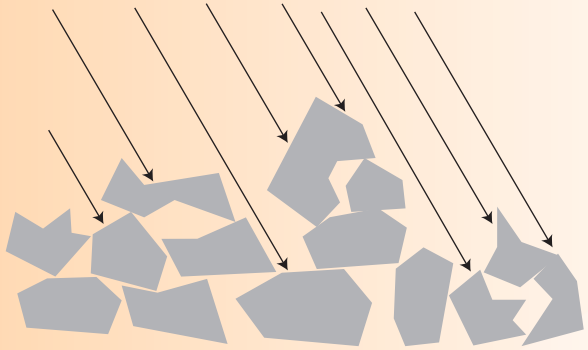
Anton V. Kulchitsky, Dana M. Hurley,
Jerome B. Johnson, Paul Duvoy, Michael Zimmerman

# Solar Wind and Regolith



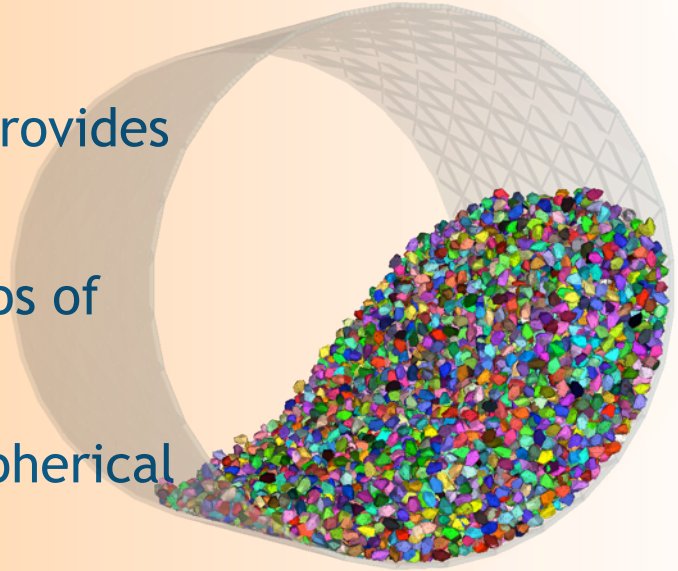

Inside the grain

How deep into regolith the solar wind particles can be implanted depending on solar wind incidence angle, regolith particle size distribution and porosity?



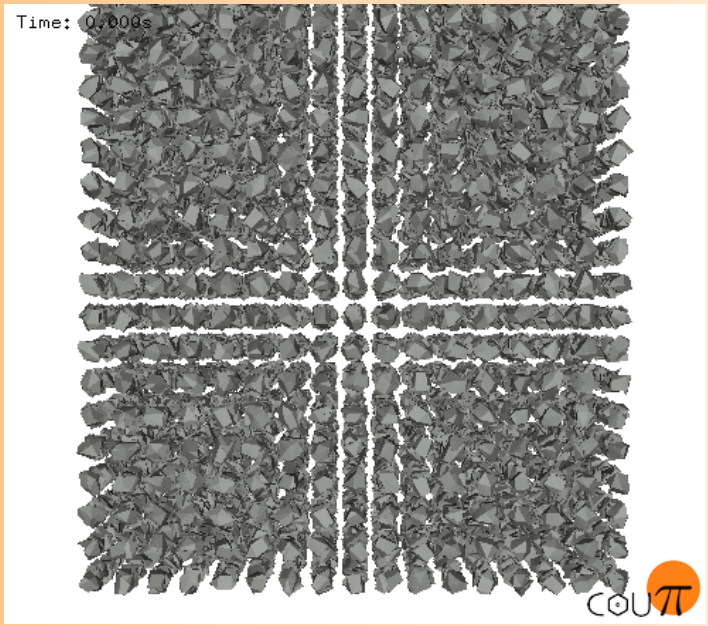
# Discrete Element Method

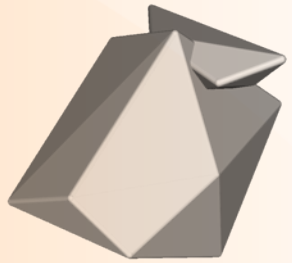
- Can represent each individual particle of granular material
- Computes forces on contacts and provides full dynamics integration
- COUPi model allows different groups of particles with different behavior
- May use polyhedral particles and spherical particles together

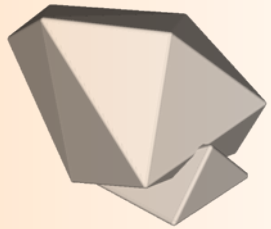


# Regolith Model

- Particles are simplified models of GRC-3 CT scans
- Regolith beds are generated by gravitational deposition

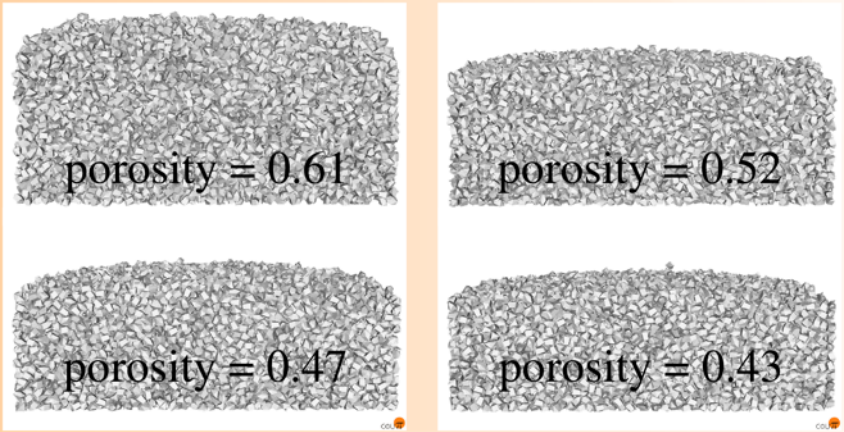




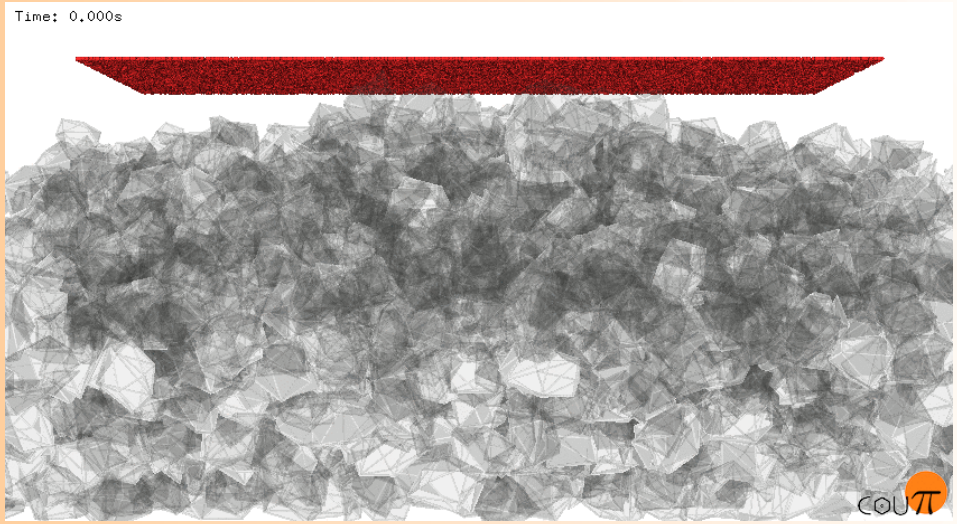
# High Porosity Regolith

- Challenge to produce required porosity consistently
- Material properties like friction and cohesion adjustment
- Modeling sieves to achieve even surface



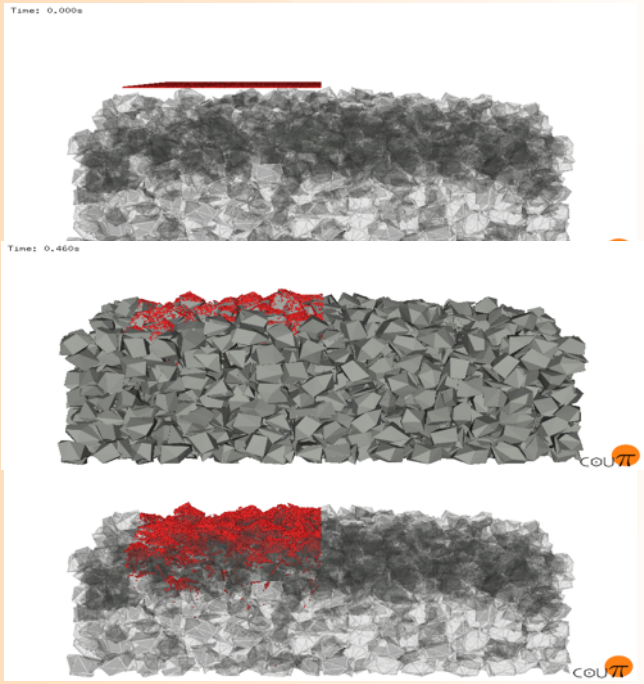
# Solar Wind Particles Implantation

- Protons are represented by points (very small spheres)
- Randomly generated above the surface
- Stop moving as they touch a regolith particle



# Implantation Rate Computation

- We analyze the vertical distribution when all particles stop
- Method: divide the vertical scale in segments and count particles within those segments



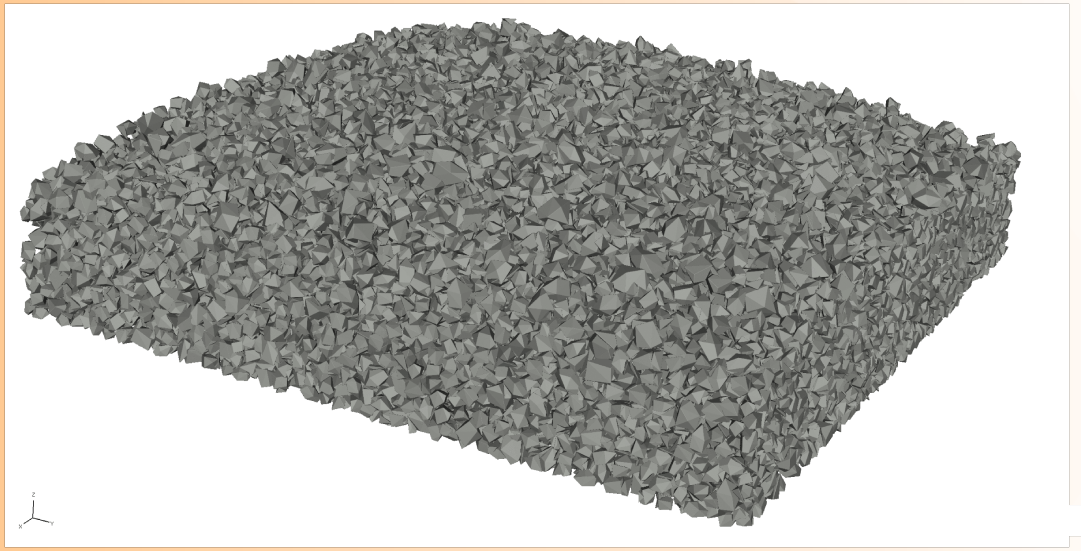
# Simulation Stages

- Deposit particles to form regolith adjusting friction and cohesion to achieve required porosity
- Generate protons as points just above the regolith
- Set the constant velocity vector for the protons and “shoot” them into the regolith
- Compute vertical distribution of protons when all protons stop moving in terms of mean particle equivalent diameter:

$$d = \left(\frac{6V}{\pi}\right)^{1/3}$$

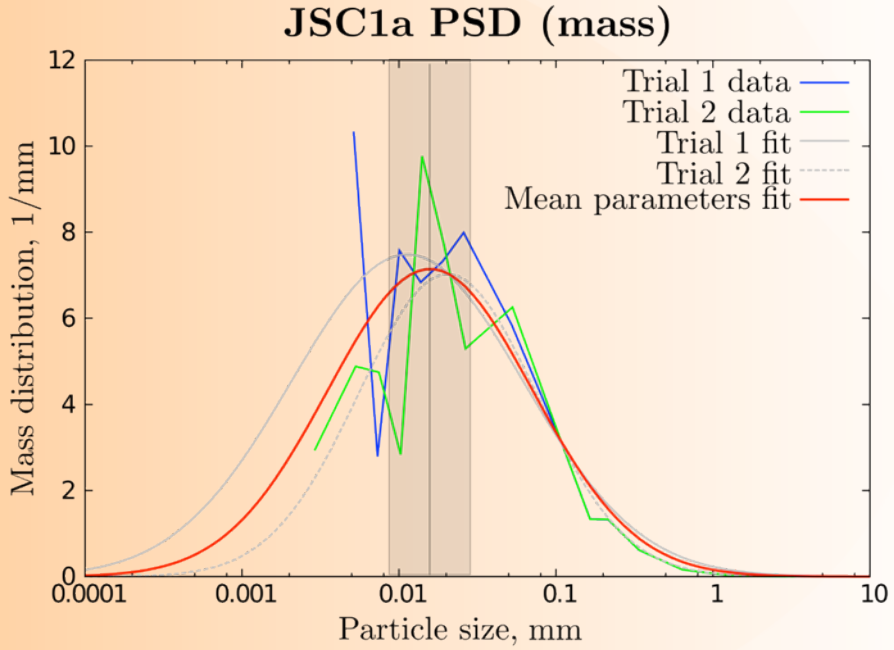
# Surface Definition

- Envelop surface around regolith particles to represent the ground 0



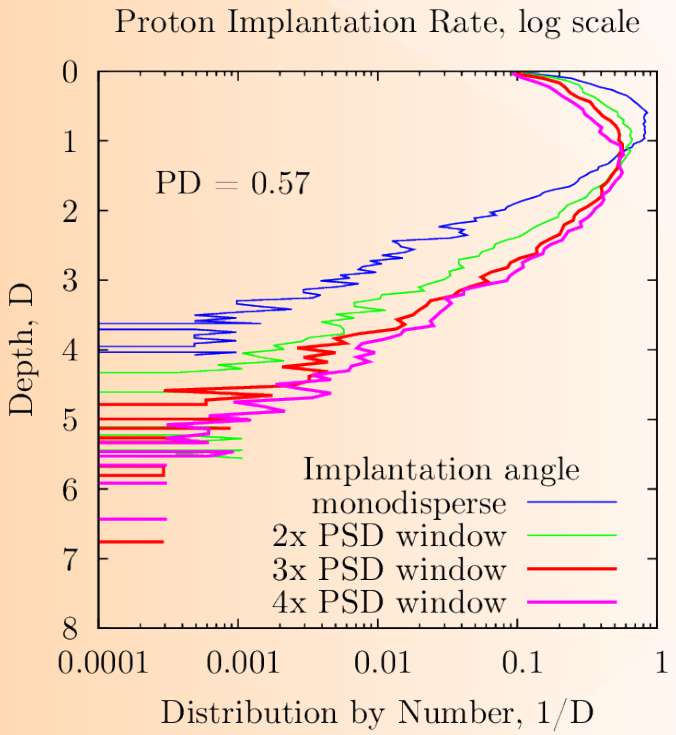
# Particle size distribution

- Log-normal distribution resembles JSC1a simulant PSD measured at NASA GRC
- Cut window in distribution around its maximum symmetrically in log scale



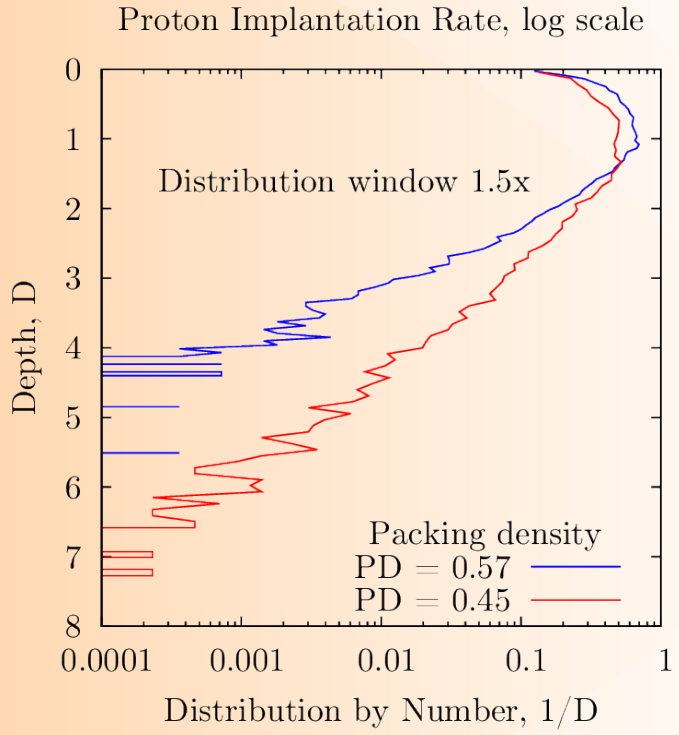
# PSD Influence

- Comparing different PSD while controlling the packing density (porosity)
- Wider distribution range allows protons to reach deeper in regolith
- There is not a significant difference for PSD window wider than 3-4x.



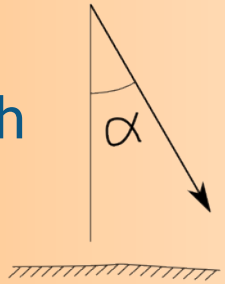
# Packing Density Influence

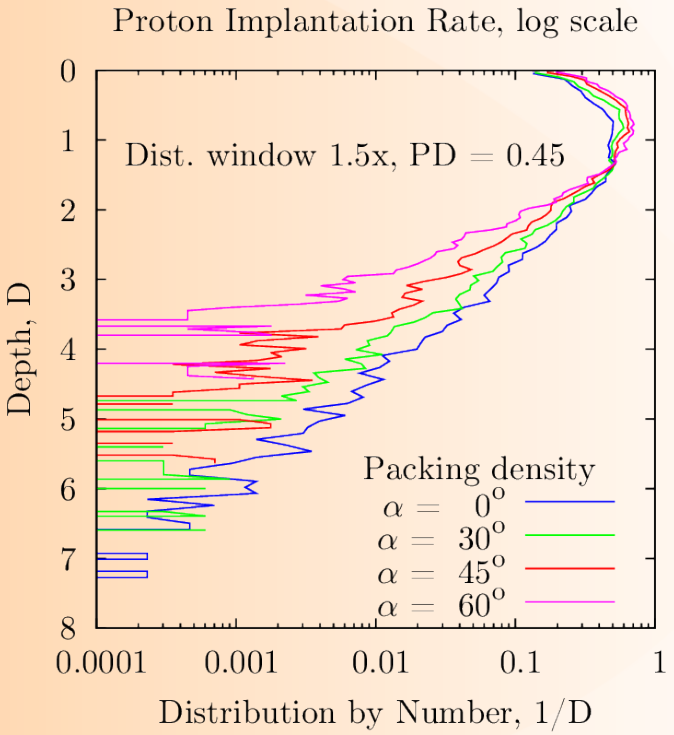
- Packing of the particles strongly affects how many protons reach deeper layers
- We detect particles as deep as 8 particle layers for porous material



# Incidence Angle Influence

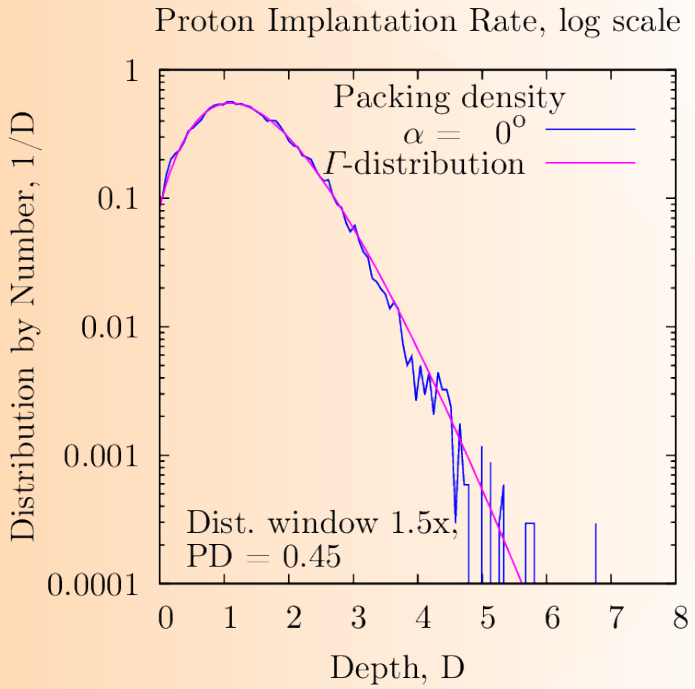
- Implantation rate depth decreases with increasing incidence angle
- The protons still can penetrate into 4-5 layers



# Gamma Distribution

- Gamma-distribution provides good fit for numerical computations
- It reduces the parameter space to 3 parameters
- The analysis of parameters is our next step




$$f_\Gamma(x + x_0; k, \theta) = \frac{1}{\Gamma(k)\theta^k}(x + x_0)^{k-1}e^{-(x+x_0)/\theta}$$

# Conclusions

- Discrete element method is adopted to compute the implantation rate for different layers of lunar regolith
- The penetration depth of protons strongly depends on porosity and 1/100,000 of all protons reach 7-8D and lower layers of particles.
- Wider particle size distribution provides deeper penetration of protons (perhaps around large particles)
- Gamma-distribution well fit into the implantation rate effectively reducing the parametric space to study